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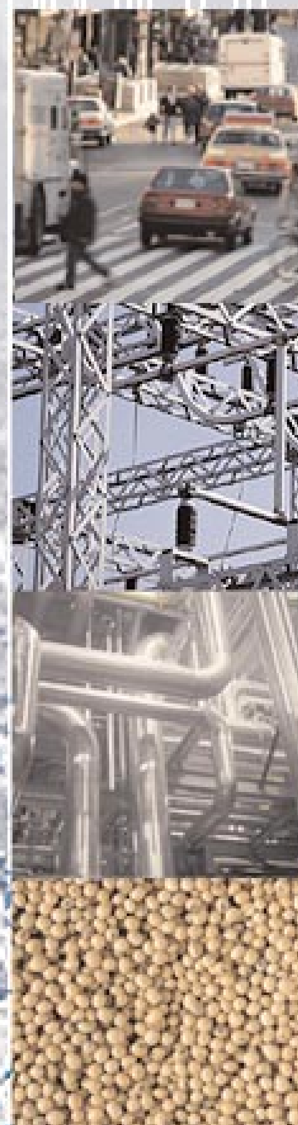
Biobased Products and Bioenergy Roadmap

Framework for a Vital New U.S. Industry



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U.S. industries—from manufacturing to services to high technology—depend on secure, reliable supplies of energy and materials. By augmenting fossil fuels, biomass resources can contribute substantially to the diversity of our nation's energy sources and the strength of our future economic growth.

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Preface

The Biobased Products and Bioenergy Roadmap is the result of an 11-month process driven by an advisory team of industry executives, with inputs from nearly 100 representatives of agriculture, industry, academia, national laboratories, government agencies, and other organizations. Their goal: to create an overarching executive-level plan for an integrated bioenergy and bioproducts industry.

This effort began in St. Louis, Missouri, in the summer of 2000, with a workshop of over 70 people. A group of 25 volunteers met in the fall of 2000 to begin consolidation of the rich thinking that emerged from the original workshop. From there, the industry advisory team worked together to draft this Roadmap, which was vetted by everyone involved from the start.

The Roadmap outlines strategies for achieving the bold targets set by industry leaders in an earlier document, the Biobased Products and Bioenergy Vision. It complements the more targeted roadmaps already published or under way with the sponsorship of the U.S. Department of Energy, which focus on specific feedstock production sectors or end-use applications.

Executive Summary

Sustainable development is widely acknowledged to be an essential future platform for energy security, industrial productivity, material availability, and continued economic health. A critical component for success will be the use of renewable biologically based sources for basic inputs in the generation of power, fuels, and products.

Existing production systems have been designed primarily for the use of nonrenewable input sources, such as fossil fuels. Broad implementation of systems that also use biobased sources appears to pose major hurdles at present.

Traditionally, the power, fuels, and chemicals industries have been relatively distinct from each other. In contrast, the biobased products and bioenergy industry is likely to be more tightly integrated, with production facilities that exploit the economies of producing multiple products from multiple feedstocks.

Developing such an integrated industry will be profoundly challenging—analogous to a "moonshot"—requiring bold visionary effort, simultaneous advances on multiple fronts of science and technology, massive investments in infrastructure and market development, and a foundation of supportive policies and education. However, the developers of this Roadmap believe that the reward for success is not trivial. It is nothing less than a foundation for future human enterprise.

How Our Nation Can Benefit

Benefits to our nation will be far-reaching:

- **Enhanced national energy security.** Biomass can diversify our nation's energy resources, providing the plentiful energy and raw material required for strong economic growth, and guarding against volatility of raw input costs. As a domestic energy source, bioenergy can substantially reduce our nation's dependence on imported oil, improving our balance of trade and enhancing domestic employment.
- **Improved environmental protection.** By offsetting fossil fuel use—and related emissions of nitrogen oxides, sulfur dioxides, and other pollutants—biobased products and bioenergy can have a large impact on the successful implementation of clean air and clean water policies. Further, by increasing the cultivation of carbon-fixing plants, a strong biobased products and bioenergy industry will help reduce greenhouse gas emissions that contribute to global climate change. It will also provide a productive avenue for using agricultural, industrial, municipal, and forestry wastes, reducing the need for landfilling and waste burning.
- **Rural economic growth.** Growth in biobased products and bioenergy will stimulate rural development efforts in farming, forestry, and associated service industries. Producers will realize more value from their crops and crop residues. Rural areas can also benefit from local production of bioenergy and biobased products.
- **U.S. leadership in global markets.** As an R&D leader in biobased products and bioenergy, the U.S. will be positioned for a strong presence in emerging global markets for these technologies.

Supportive Trends

Several key trends support the emergence of an integrated biobased products and bioenergy industry:

- **Rapid progress in biotechnology.** In just the past decade, the economics of bioproduction and value of bioproducts have become increasingly attractive, thanks to technology developments. Yet far greater improvements are on the horizon. Advances in such fields as genomics, proteomics, metabolic engineering, enzyme design, molecular evolution, computational biology, and bioinformatics hold great promise for multiplying biomass feedstock production, enhancing conversion efficiencies, and creating high-value bioproducts. The U.S. is well-positioned to lead this revolution, with the strongest biotechnology infrastructure in the world.
- **Increasing potential of biobased products and bioenergy.** Biobased products and bioenergy can be sustainable alternatives to supplement many petroleum-based products. Potential products include chemicals and materials, fuels for transportation and heating, and power (IGCC, fuel cells, microturbines). Biomass is also a potential fuel for hydrogen production. In the longer term, biobased materials can be designed for particular end-use requirements, with the potential to improve processing efficiency or to add incremental value in particular uses and applications.

- **Growing interest in distributed production.** Biobased products and bioenergy are well-suited to distributed (local) production and output generation, near the sources of biomass cultivation. Technically, this fits well with the "distributed" nature of primary solar energy capture. In addition, this approach fits with policy trends, such as power industry deregulation, that encourage decentralization. In some cases, biobased products and bioenergy will allow "green power" options, while in other cases, biomass will be closely integrated with conventional fossil-based resources.
- **Emerging technologies for efficient biorefineries.** Historically, biobased resource use was often focused on a single input-output situation, which typically resulted in poor economies for the system. Today, the trend is toward multisource biobased inputs with processing streams that lead to several output products—each contributing to the economic return. For example, a biorefinery might take a biobased feedstock and convert it to several chemical products, ethanol fuel, and power and heat to operate the biorefinery and perhaps sell some power to the power grid. Such biorefinery processes can be developed for different operational scales, allowing optimization in size and distribution of location.

Critical Success Factors

Key success factors will include:

- **Supportive government policies.** Agriculture, energy, environmental, and other relevant policies must be aligned across multiple federal agencies (e.g., DOE, EPA, USDA, NSF, DOC), as well as state and local governments.
- **Significant R&D funding and capital investment.** Billion-dollar investments will be required in multidisciplinary research, development, and demonstration, and in new infrastructure.
- **Leadership.** Bold, organized leadership by private-sector stakeholders will be essential.
- **Sustained federal support.** The federal government must have a central role in providing sustained support for research and development, public education, and incentives for producers and processors to spur market development. Federally supported mechanisms will be vital in spurring first-of-a-kind commercial-scale deployments.
- **Federal coordination and integration.** Federal agencies must improve how they work with each other, and with the private sector, to coordinate and integrate the development of a biobased products and bioenergy industry.
- **Strategic partnerships.** Cross-industry partnerships will be needed to bring together the required diverse capabilities (e.g., partnerships between crop producers, processors, and power, fuel, or product companies).
- **Demonstration of life-cycle benefits.** Demonstration of life-cycle benefits will be important in achieving better public acceptance of plant sciences and intensive management, including the feasibility of effectively balancing biomass, food, and feed production.
- **Major educational efforts.** Stronger educational programs are needed at all levels (elementary and secondary, college, graduate level, professional) and across multiple disciplines (biology, agronomy, computational science, bioprocess engineering, chemistry, chemical engineering, sustainability, ecology).
- **Accelerated innovation and deployment.** Faster deployment of currently available technologies—as well as R&D of new technologies—is required to achieve improvements in cost, efficiency, and value.
- **Public outreach and marketing.** Major public outreach and marketing efforts are needed to communicate the uses and benefits of biobased products and bioenergy to stakeholders and consumers.

Our nation has an opportunity to develop and introduce supplements to fossil fuels and petrochemicals while conditions are relatively stable. If we are to fully realize the benefits of biobased energy and products in coming decades, it is imperative that we start now to invest in research, development, and demonstration of key technologies, as well as in market and infrastructure development.

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Our Nation's Biobased Future

Fossil fuels powered phenomenal growth in 20th century America. Today, fossil fuels remain the predominant source of our transportation fuels, heat, electricity, and chemicals.

In this century, our nation must augment fossil fuels with new energy sources and chemical feedstocks if we are to sustain our economic vitality and quality of life. Otherwise, in the face of accelerating global demand for products and energy, finite reserves of petroleum and natural gas will inevitably become a constraint to growth, as well as a potential cause of international conflict.

This Roadmap outlines a set of strategies and priority actions to further the bold targets set in the Biobased Products and Bioenergy Vision (see below). The Vision foresees the emergence of a dynamic new industry in the United States that can enhance our energy security, environmental quality, and rural economies. This industry will use biomass—trees, crops, crop residues, animal wastes, municipal solid wastes, aquatic biomass, and other biomass—as a renewable source of energy and raw materials to manufacture a significant share of our nation's power, fuels, chemicals, and other vital products. Because of their great diversity and versatility, biomass resources not only can be used to make products virtually identical to any of those derived from fossil fuels, they also can yield novel products with unique, high-value characteristics.

The visionary goals, by design, chart an ambitious course. They were defined not by extrapolating current trends, but by posing a "gap" scenario that looks at future U.S. market needs. The scenario: *What if* our nation's fossil fuel use were to stay constant from now through 2050, while demand for energy and petrochemical products continues to grow as projected? Could we fill the resulting gap using biobased products and bioenergy?

Meeting the visionary targets would fill the energy and raw materials gap by 2020. The 2020 target, which represents a 10-fold increase in the use of bioenergy and biobased products versus 2000 levels, is the central goal addressed by the strate-

The Biobased Products and Bioenergy Vision

Biomass resources—naturally abundant throughout our nation—will be a cornerstone of a new energy economy in the United States. An integrated biobased products and bioenergy industry will produce power, fuels, chemicals, and materials from crops, trees, and wastes, helping to grow the U.S. economy, strengthen U.S. energy security, protect the environment, reduce greenhouse gas emissions, and revitalize rural America.

Visionary Goals

By **2010**, increase the use of biobased products and bioenergy in the U.S. by **3-fold** over 2000 levels.

By **2020**, increase the use of biobased products and bioenergy in the U.S. by **10-fold** over 2000 levels.

With this significant increase, biomass would account for 25 percent of our nation's total energy consumption (including feedstocks). The U.S. would create the foundation for a secure energy future and establish its worldwide leadership in biobased products and bioenergy technologies.

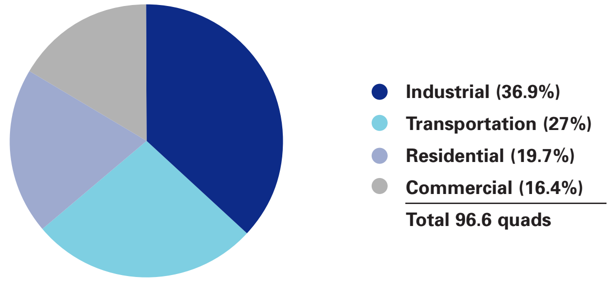
By **2050**, increase the use of biobased products and bioenergy in the U.S. by **another 2-fold to 3-fold** over 2020 levels.

At this level, biomass would account for as much as 50 percent of our nation's total energy consumption (including feedstocks). The U.S. would have the capacity to be fully energy-independent, and U.S. companies would be dominant players in substantial worldwide markets for systems and services related to biobased products and bioenergy.

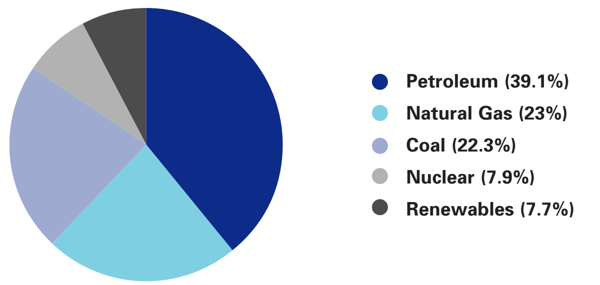
gies in this roadmap. The 2050 goal is an illustration of the significant potential of biomass in enhancing energy security, environmental quality, and rural economic development. The 2010 goal provides an early checkpoint along the path to the Vision.

Achieving the visionary goal for 2020—a 10-fold increase in biobased products and bioenergy use—would vastly increase U.S. energy self-sufficiency. By 2020, the U.S. would use about 30 quads worth of primary energy for bioenergy and biobased products, enough to meet incremental demand growth for petroleum fuels and petrochemical products while keeping fossil energy use steady at current levels. As a frame of reference, current primary energy consumption in the U.S. is 97 quads (see pie charts) and is projected to grow to 127 quads by 2020.

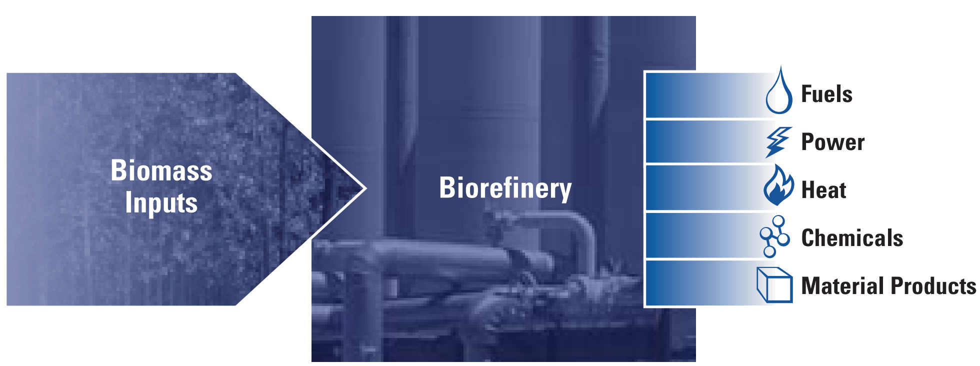
U.S. Primary Energy Input Requirement by Sector[1]



U.S. Primary Energy Input by Source



Tomorrow's biorefineries will use advanced processing strategies to efficiently co-produce a diverse and flexible mix of fuels, electricity, heat, chemicals, and material products—each contributing to the economic return. The biorefinery concept has already proven successful in the agricultural and forest products industries, where systems provide not only primary food, feed, fiber, or material products, but also heat and electricity to help run the operations.



[1] *Source: Energy Information Administration,* Annual Energy Review 1999

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How Much Growth Is Envisioned?

Biomass is currently the source of just over 3 quads of primary energy in the U.S. After conversion, this biomass produces the equivalent of 1.8 quads of power, fuels, and products. Achieving a 10-fold increase by 2020—to 18 quads of bioproducts and bioenergy use—will require enormous private-sector investments in new infrastructure for producing and transporting feedstocks, and for processing and distributing biobased products and bioenergy.

Feedstock requirements. A recent analysis concluded that the equivalent of about 16 quads of biomass—beyond that used for food, feed, and conventional lumber, pulp, and paper—is available in the U.S. (see table). At an average conversion efficiency of 50 percent, this quantity of biomass could produce about 8 quads of bioenergy and biobased products. So, at existing conversion efficiencies, 36 quads of biomass feedstocks would be required to meet the 2020 vision of 18 quads of bioenergy and biobased products, or about double year-2000 levels.

Where might this increase come from? Several factors make it likely that our nation can produce enough biomass to meet the 2020 goal while staying within the limits of our current arable land resources. These factors include:

- **Increases in conversion efficiencies:** With continued processing and conversion improvements, more output (in power, fuels, and products) will be produced per unit of biomass. So the actual quantity of feedstock required will be less than 36 quads.

While the overall visionary target for 2020 is a 10-fold increase in the use of biobased products and bioenergy, the actual magnitude of contributions from different biomass sources will vary greatly. Likewise, the growth in bioproducts or bioenergy will vary from one output category to another. The Vision makes no assumptions or predictions about the split among products, fuels, and power. The 2020 numbers in this chart are illustrative only.

Categories of biobased products and bioenergy	Current use in the U.S. (approximate)	Illustrative levels of use by 2020
Carbon-based chemicals and materials[2]	18 billion pounds = **0.2 quads**	180 billion pounds = **2 quads**
Fuels	Ethanol: about 1.7 billon gallons from corn = **0.2 quads** Biodiesel: about 2-3 million gallons = **0.0004 quads**	**2 quads**
Power and heat[3]	Total output (actual use) = **1.4 quads (400 million megawatt-hours)**	**14 quads (4 billion megawatt-hours)**
Total use (output)	**~1.8 quads**	**~18 quads**

[2] This figure excludes conventional forest products (lumber, pulp, and paper), which are not part of the Vision goals. Bioproducts account for about 3 percent of the more than 300 billion pounds of chemicals and materials—including about 90 billion pounds of plastics—currently produced. The energy value is expressed in terms of material use in the final product and does not include the process energy or material losses in the process.

[3] Although conventional forest products (lumber, pulp, and paper) are not included in the chemicals and materials category (above), the power and heat used to manufacture them is included in this figure.

- **Increases in conventional crop yields and energy crops:** Current productivity trends (2 percent gain per year) would equate to an increase in conventional crops of about 40 percent by 2020. As yields increase, some biomass may become available for biobased products and bioenergy if production exceeds food and feed needs. Emerging biotechnologies have the potential to vastly increase yields beyond this level, for both conventional crops and specially tailored energy crops. Various estimates for the potential of biotechnologies project yield potential of two to five times current yields.
- **Increased utilization of crop residues and animal byproducts:** Actual crop residues currently are 400 million dry tons per year, nearly three times the level included in the estimate (below), which assumes retention of two-thirds of residues to ensure good quality soil condition. The actual amount required for optimum soil condition is still under experimental investigation. Another potential source of biomass not reflected in the estimate below is animal fats from rendering and recycled restaurant greases, which represent about 0.2 quads of primary energy.
- **Opportunities to utilize biomass from aquatic sources:** Seaweed, algae, and other aquatic plants are potentially enormous sources of biomass feedstocks. Aquatic photosynthetic organisms also can directly produce products and fuels (e.g., hydrogen).

Capital Investment Requirements

Achieving the Vision will require significant capital investment. For example:

Assume that by 2020 our nation will be generating an additional 10 quads of electricity from biomass. This equates to 1,800 new power plants with a capacity of 100MW to 300MW each. The total capital required in today's dollars could be about $175 billion. **[MUST VERIFY]**

To put this in perspective, a total of $9.7 trillion in capital was invested in the U.S. between 1980 and 1998. About $1 trillion of this was invested in U.S. electric utilities. The Department of Energy estimates that over the next 20 years, U.S. electricity demand will increase by 45%. That rise in growth will require over 1,300 new power plants.[4]

U.S. Feedstocks Quantity Available by Biomass Type[5]	**Millions of dry tons per year**
Agricultural crop residues (corn stover, wheat straw, rice straw, cotton stalks)	156
Forest residues	84
* **AGRICULTURE CROPS TO COME**	**??**
Primary mill residues (excludes portion currently used for fuelwood, fiber, and miscellaneous by-products)	2
Other wastes (includes unused organic fraction of municipal solid waste, waste wood from construction and demolition, and urban tree residues)	161
Biogas (includes landfill gas, digester gas, and sewage gas)	11
Sludge (includes manure and biosolids)	50
Potential energy crops[6] (primarily switchgrass; also hybrid poplar and willow)	159
Total (millions of dry tons per year)	**623**
Total quads	**16 quads**

[4] *Testimony of Secretary of Energy Spencer Abraham to the Department of Commerce, March 19, 2001.*

[5] *Based on a draft analysis by Arthur D. Little for the Biomass Research and Development Board. Results are for biomass at a cost of up to $50 per dry ton delivered. Market prices will strongly influence actual supplies.*

[6] *This is an estimate of feedstocks that could be obtained from potential energy crops on available lands today. This biomass source does not actually exist at the current time.*

What Will the Vision Require?

Incremental advances will not be adequate to achieve the visionary goals for biobased products and bioenergy. What is called for is nothing less than revolutionary breakthroughs, not only in science and technology, but also in infrastructure and market formation. This Roadmap outlines strategic pathways and priorities for achieving these advances, together with essential policy and education drivers. It proposes a framework for private- and public-sector partnerships to lay the foundation for a biobased future.

Realizing the visionary goals will be enormously challenging. The effort will require billions of dollars in investments in research, development, and infrastructure. It will require bold leadership, effective teamwork, multidisciplinary research, and a purposeful integration of science, technology, and entrepreneurship. And it must engage our education system in developing vital understanding and skill sets across multiple disciplines. In short, it must fully leverage our nation's capabilities and resources across the public and private sectors.

Technology Development

Our nation must overcome challenging technical hurdles to produce bioenergy and bioproducts at the scale envisioned for 2020. We must draw on a larger and more diverse range of biomass resources than those typically used today, including waste materials, energy crops, and plants and microorganisms specifically designed to yield desired constituents. We will need advanced feedstock production and characterization methods to improve the availability, reliability, and consistency of biomass supplies. Increasingly efficient processing and conversion methods will also be required, as well as systems engineering and scale-up of integrated biorefineries and other co-production models.

Across the board, there will be a need to accelerate promising technologies through R&D to commercial-scale application. Aggressive research investments are urgently needed now, in order to meet the visionary targets for the coming decades. Targeted R&D opportunities include:

- Increased availability of conventional lignocellulosic biomass feedstocks at reduced costs, through improvements in production, harvesting, collection, densification, transportation, and storage.
- Cultivation of fast-growing switchgrass, hybrid poplar and willow, and other fast-growing plants that can produce high yields of cellulose and other desired constituents per acre.
- Development of new biomass feedstocks optimally designed for specific energy or product end uses, and cultivation of aquatic organisms.
- Improved cost efficiency and energy efficiency in processing and conversion processes, through scaled-up deployment of proven methods as well as development of novel concepts.
- Development of advanced processing strategies for co-production applications in biorefineries.

Progress in isolated areas will not be sufficient. To address the complex requirements of an integrated biobased products and bioenergy industry, research and development must be multidisciplinary, focused, and coordinated.

Market Development

Like other emerging technologies, biobased products and bioenergy must navigate a development curve, reaching a point at which their demonstrated value makes them successful and competitive in the marketplace. Yet these products face an unusually high hurdle in becoming a viable supplement to fossil fuels. Throughout the last century, our nation has invested in a sophisticated infrastructure for researching, producing, processing, securing, distributing, and utilizing fossil energy. As a sunk cost, this infrastructure currently favors the continued use of fossil energy and petrochemicals in cost comparisons with bioenergy and biobased products.

At some future point, when crude oil prices increase due to declining supply, and when environmental results of increased use of fossil sources are factored into their costs, comparative-cost equations can be expected to favor bioenergy and biobased products. Long before this point, however, our nation will need to ramp up its investment in a bioenergy and biobased products infrastructure if these renewable resources are to be a significant part of our future economy.

Our nation currently uses biomass for about 3 percent of its energy consumption, most significantly in the co-production of heat and power in the forest products industry. Recent developments will spur further market growth. For example, biotechnology has yielded a new process that can make polylactic acid (PLA) resins cost-competitive with current petrochemical-based products. The first production plant is currently under construction by Cargill Dow LLC in Nebraska. In the biofuels area, methyl tertiary butyl ether (MBTE), the most widely used gasoline additive to improve air quality, is being phased out in California and key northeastern states because of water contamination from leaking gasoline storage tanks. Ethanol is being considered as an alternative additive, potentially increasing demand for ethanol by as much as 1.2 billion gallons per year over the current demand of 1.7 billion gallons. Another promising near-term growth opportunity is in power generation, where biomass can be co-fired in coal- or natural-gas-fueled plants, either as a solid or after gasification.

To achieve the Vision targets, market growth must be greatly accelerated. While market development strategies will differ for biopower, biofuels, and biobased products, key challenges across the board include:

- Creating market demand and preference for biobased products and bioenergy, based on superior life-cycle value.
- Establishing market qualifications and standards for bioenergy and biobased products.
- Identifying customer needs to drive the design of bioproducts.
- Jump-starting the market for biomass by providing incentives for producers.

Ultimately, the biobased products and bioenergy industry will be dynamic and self-supporting. Returns to our nation will include enhanced energy security and environmental quality, stronger rural economies, new domestic employment opportunities, enhanced balance of trade, and a strong position in global markets for biobased technologies.

Policy and Education Drivers

On the public-sector side, **supportive government policies**—aligned across multiple agencies—will be essential in catalyzing both market development and technology development, and in attracting vast private-sector investments.

Policies governing a wide range of areas—from transportation to rural development, from agriculture to commerce, from environmental protection to energy security, and from land conservation to taxes—will have an impact on the future of biobased products and bioenergy. An effective policy framework will reduce market barriers to biomass, incentivize private investments, and establish science-based standards for bioproduct quality, performance, and safety.

The federal government can also play a vital role in education and outreach, providing information on the benefits of biobased products and bioenergy to states, communities, farms, industries, and consumers. For example, the government might promote labeling or biobased products through a federal program similar to Energy Star, to support the development of market demand.

Above all, **significantly increased levels of public investments** will be needed for research and development and for risk-sharing in first-of-a-kind commercial-scale demonstrations. This Roadmap envisions annual federal funding of $1 billion for research, development, and demonstrations of bioenergy and biobased product technologies, an amount equivalent to the current annual federal RD&D spending on fossil fuel technologies and chemical sciences.

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Vision and Roadmap Development

Both the Biobased Products and Bioenergy Vision and the Roadmap have been developed in industry-led processes, involving representatives of biomass production sectors (primarily forestry and farming) and market sectors (power, fuels, and products). A broad range of organizations—including academic, research, and government organizations, as well as industry—provided inputs and comments throughout the development process.

Framing
Initial industry advisory team defined objectives and process

Vision Workshop 1
March 1999, St. Louis
Brainstorming, 90 attendees

Vision Workshop 2
June 1999, Washington, D.C.
__*attendees*

Vision Workshop 3
December 1999, Washington, D.C.
__*attendees*

Draft Vision
Review open to all participants

Roadmap Workshop 1
June 2000, St. Louis
Brainstorming, 90 attendees

Roadmap Workshop 2
August 2000, Chicago
25 attendees

Roadmap Workshop 3
January 2001, Chicago
9-member advisory team

Roadmap Workshop 4
February 2001, Washington, D.C.
9-member advisory team

Draft Roadmap
Review open to all participants

Technology Development

Advances in technology will make the economics of biobased products and bioenergy increasingly attractive. Developments in genomics, proteomics, metabolic engineering, agronomy, agriculture and silvaculture practices, separations technology, fermentation, gasification, pyrolysis, and other fields hold great promise for increasing production efficiencies, reducing costs, and enhancing product value. Addressing the complex challenges of an integrated biobased industry will demand multidisciplinary efforts, crossing traditional boundaries of science, technology, and entrepreneurship.

This section of the **Roadmap** identifies key technology development and deployment challenges over the next 20 years and beyond, focusing on opportunities where private and public research, development, and demonstration partnerships are considered most critical. Aggressive investments are urgently needed in the near term, in order to meet the visionary targets for the coming decades.

Strategic results, goals, and tactical actions are identified for four interrelated areas:

- **Plant science:** Scientific advances will make it possible to produce existing and modified plants, trees, and residues with characteristics increasingly well-suited for feedstocks. Crops can be modified to yield higher levels of more desirable constituents, to produce novel high-value constituents, to facilitate component separation, and, possibly, to increase their energy density. Such breakthroughs can dramatically reduce final costs of biobased products, fuel, and power. New technologies also can increase biomass yield per acre while reducing required inputs. The results: lower biomass costs, and enhanced capabilities to produce energy, products, food, and feed, while reducing the environmental impacts of agriculture, silviculture, and aquaculture. All of these advances must be made while maintaining biodiversity and ensuring the safety and sustainability of the technologies utilized.
- **Feedstock production:** Improved practices in agriculture, silviculture, and aquaculture can play a significant role in increasing yields while reducing required inputs. For example, tomorrow's fertilization technology might involve new materials or encapsulated slow-release technology to improve uptake efficiency and reduce runoff; and irrigation technology might reduce the amount of water required. Reduced tillage has already shown to have specific advantages. To achieve the great increases in biomass feedstock required by the Vision, many issues must be resolved in harvesting, collection, storage, and transport. Current methods result in low densities of desired components, high transportation costs, and potential storage stability issues. Preprocessing might be done "on the farm" or even during harvesting to densify, dry, and perhaps initially separate biomass components. New transportation schemes might include pumping a fluid slurry or "pelletizing" biomass locally.
- **Processing and conversion:** Advances in biomass conversion processes over the past two decades have been dramatic. For example, the cost to produce sugar for ethanol and other products from lignocellulosic feedstock has been reduced by a factor of six since 1980. Other advances are now being employed in commercially viable operations, including biomass co-firing with coal, and production of polylactic acid (PLA) plastic. The pulp and paper industry will soon demonstrate black liquor gasification technology to produce steam for process use as well as electricity. Now, further development in processing and conversion technology is needed to achieve the Vision. Most biomass is solid, requiring improved material-handling systems at the front end of conversion operations. Improvements in separations technology will reduce processing costs, waste, and environmental impact. Promising developments in biomass gasification, combined with new turbine and heat recovery technology, can increase energy conversion efficiency. Further reductions in the cost of sugars derived from biomass will make ethanol and new fermentation products cost-competitive. Research to produce fuels and products through biomass gasification and pyrolysis continues to move forward. Continuing breakthroughs in biotechnology make fermentation and isolated enzyme catalysis more cost- and energy-efficient.
- **Product uses and distribution:** Some products that can be produced from biomass are novel materials, such as new polymers or composites of fibers or other biobased matter with fossil-based plastics. Opening market opportunities for such new materials will require an understanding of their best function, use, and characteristics. Biobased chemicals and materials will be accepted faster in the marketplace with appropriate standardized tests and specifications. Once technology is developed, investment in deployment and infrastructure is needed to reap the benefits.

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Technology: Plant Science

Strategic Result

Increase the availability, cost-effectiveness, and appropriateness of feedstocks for sustainable biobased products and bioenergy applications, through innovations in plant sciences and other relevant primary product and energy sources.

Goal 1

Produce existing, modified, and new crops (and residue materials) that have desired characteristics to fit the relevant processing system and/or use.

Tactical Actions

By 2010	By 2020	By 2050
Demonstrate to the general public that alterations to metabolic pathways can provide desired materials for biobased inputs in a safe and scientifically sound manner.	Design and implement alterations to metabolic pathways in 3 or more existing plant types: to increase yield of materials with desired characteristics by 25% or more.	Design and create novel plant types for a 50% improvement in conversion efficiency for the production of biobased products, biopower, and biofuels.
Identify the major desired plant characteristics and traits for use in biomass combustion/gasification, and/or as inputs for biorefinery processing, and produce selective crops for at least 10M acres.	Produce a suite of selective, cost-competitive, broadly adaptive crops for biobased products and bioenergy (at least 50M acres).	Use aquatic and other nonagricultural-based biomass to produce biobased products and bioenergy.
Identify and implement 5 projects that leverage existing genome research for relevant biobased products and bioenergy applications.	Isolate 50 or more specific genes and/or regulatory elements related to biobased products and bioenergy feedstock production in crops and trees.	
Identify methods for altering carbon flow into higher energy compounds such as lipids.	Increase efficiency of photosynthetic energy capture by 10-20%.	Increase efficiency of photosynthetic energy capture by 2-fold or more.
	Alter carbohydrate composition: e.g., change lignin and/or cellulose content by 50% depending on end-use need.	Improve production efficiency (yield per unit input used) by at least 3-fold over the recorded average for crops in 2000.

Goal 2

Create robust, multi-product plants and organisms that optimize yield per unit input in a sustainable manner, and that can be produced without compromising food, feed, and forestry requirements.

Tactical Actions

By 2010	By 2020	By 2050
Improve efficiency of input resource use by 20% in crops grown for biobased uses.	Improve plant efficiency use and/or input delivery systems to reduce water use by 2-fold, nitrogen input by 5-fold, salt tolerance by 3-fold.	Optimize plant reaction to ensure sustainable production in response to climate change.
Increase productivity per acre by a factor of two for selected crops being used for bioenergy and biobased products.	Increase productivity per acre by a factor of 3 for selected crops being used for bioenergy and biobased products.	Increase productivity per acre by a factor of 4 for at least 3 bioproduct/bioenergy crops.
Identify the top issues related to competition for end uses (food, fiber, fuel, power, products, etc.), and identify potential solutions.	Implement solutions to the top 3 issues related to competition for end uses.	***Milestone:*** *Altered composition and production efficiency such that competition between plant type uses is not an issue.*
Understand genetic diversity by screening natural germplasm to identify genes that could be applied in improving feedstock production.	Design and implement a suite of multiple traits, multiple species, and multiple crops that can be used for biobased products and bioenergy.	Create novel diversity through gene shuffling to improve 3 or more species as economic feedstocks.

Goal 3

Create biobased products and bioenergy resources that are sustainable with minimum impact on the environment and biodiversity, through advancements in fundamental scientific knowledge of plants and biological primary-energy-capture systems.

Tactical Actions

By 2010	By 2020	By 2050
Identify potential concerns in relation to environmental issues, and demonstrate that designed biobased product and bioenergy systems do not have net negative environmental and sustainability consequences.	Ensure that bioproduct and bioenergy systems are generally accepted as beneficial to the environment and sustainability.	
Determine potential issues related to biodiversity.	Address any major issues that arise on both local and global scales.	***Milestone:*** *Bioenergy and bioproduct systems—including high-intensity production—are recognized as beneficial to the environment and sustainable development.*

Technology: Feedstock Production

Strategic Result

Implement a cost-effective infrastructure for production, collection, storage, identity preservation, pre-processing activities, and transportation of feedstocks for biobased products and bioenergy applications.

Goal 1

Optimize yields of biobased feedstocks with the desired characteristics through improved production methods.

Tactical Actions

By 2010	By 2020	By 2050
Identify and initiate production optimization on key crops for biobased products and bioenergy.	Increase yield of useful biomass per acre by a factor of 3 or more.	Achieve economic production technologies for aquatic systems.
Establish optimum agronomic practices for sustainable production including existing residue removal (optimize inputs such as fertilizer, water, pesticides, and tillage practices).	Implement agronomic practices that provide more consistent supply (less sensitivity to stresses).	Achieve a zero-waste production system with either direct use or recycling of all components.
Understand potential environmental impacts of aggressive, intensive agriculture (e. g., soil erosion, runoff, water use).	Introduce technology to reduce nitrogen and phosphorous runoff by 80%.	Eliminate all agricultural environment issues resulting from intensive agriculture.
Understand, develop, and demonstrate the potential increase in productivity from new "crop" types.	Develop optimum practices for the production and handling of new crops, engineered crops, and forests (including pesticide, disease, and "herbicidal" systems).	Improve production efficiency (yield/unit input) by 4-fold.
Validate soil organic carbon impact for crop residue removal as a function of agronomic practices that is applicable to all U.S. growing regions.	Deliver biomass to the bioprocessing plants at a price competitive with other fuels on a fully costed basis.	

Goal 2

Identify and implement best methods for cost-effective harvesting, collection, storage, transport, and feedstock preparation.

Tactical Actions

By 2010	By 2020	By 2050
Identify main limiting factors impacting the use of plant/animal residues, and implement highest leverage solutions.	Implement additional high-impact solutions.	Implement solutions to remove any remaining inefficiency factors.
Lower unit collection and transport costs by more than 30% (vs. today).	Lower unit collection and transport costs by more than 50% (vs. today).	Implement economic harvesting and collection systems for aquatic situations.
Demonstrate prototype systems that lower harvest, collection, storage, and transportation costs by 50%.	Deploy machinery on 50% of applicable acres to cost-effectively separate residues from foodstuffs in the field.	Deploy machinery on 70% of applicable acres to cost-effectively separate residues from food in the field.
Use pre-conversion processes to increase energy-and chemical-density of raw materials as collected at the site or origin, by 5-fold or more.	Use pre-conversion processes to increase energy- and chemical-density of raw materials as collected at the site or origin, by 20-fold, either by weight or by volume.	Develop systems for extraction and recovery of valuable key components at biomass harvest site.
Evaluate practical transport innovations such as slurry pipelines or pellet systems.	Implement practical and cost-effective transport innovations.	
Evaluate potential to improve storage methods that lead to a fungible system.	Achieve minimum of two-year storage of fungible feedstock with minimum degradation.	

Technology: Processing & Conversion

Strategic Result 1

Develop economically viable separation and conversion processes for commercial use of a range of biobased feedstocks.

Goal 1

Identify and solve major front-end limitations to biobased feedstock handling and preparation for processing.

Tactical Actions

By 2010	By 2020	By 2050
Commercially demonstrate solutions to material handling issues (e.g., size reduction, drying, solids feeding to pressurized vessels etc.) for largest biomass volume contributors. Wherever possible, identify generic solutions that will apply across multiple feedstocks.	Have available as a commercial choice a range of front-end feed preparation systems that handle a range of biobased inputs in an effective, preprocessing manner.	
Implement improved, low-cost biomass analytical characterization methods with advanced sensors and fully integrative controls.		

Goal 2

Improve separation and fractionation technologies for high-throughput systems that use feedstocks with variable properties.

Tactical Actions

By 2010	By 2020	By 2050
Demonstrate 50% improvement in selectivity for physical separation methods applied to biomass feedstocks.	Implement new separation and purification processes for liquid fuels and chemicals production.	
Achieve a similar improvement for chemical separations of critical importance (e.g. nitrogen-containing constituents from fermentation streams).	Develop low-cost, practical air enrichment and gas separation technologies suitable for biomass conversion.	Improve separation and fractionation technologies for high-throughput systems that produce no waste streams.

Goal 3

Develop cost-effective and environmentally responsible conversion technologies for a suite of biobased products and output types.

Tactical Actions

By 2010	By 2020	By 2050
Identify and demonstrate methods for conversion of traditional biomass into value-added products.	Widely deploy conversion methods for designed and engineered plant constituents: e.g., small molecules, polymers.	Ensure commercial production of multiple chemicals and materials from biomass sources.
Implement methods to lower cost of biomass-derived alcohol fuels production to $0.75/gallon.	Implement conversion processes for biobased liquid fuels at cost of $0.60/gal that are flexible in using variable feedstock types.	Develop fast biocatalytic conversion systems that achieve 99% conversion efficiency.
Implement biomass co-firing at 5% of coal-firing capacity.	Implement biomass co-firing at 10% of coal-firing capacity.	
Demonstrate and deploy biomass (forest and agricultural residue) gasification combined-cycle power generation at capacities up to 1,000 dry TPD at 10 or more locations.	Increase deployment of biomass residual gasification by a factor of 50. Improve biobased power generation efficiencies through wide application of fuel cells.	
Demonstrate and deploy forest products black liquor gasification combined cycle at capacities of 2,000,000 pounds of black liquor solids per day and larger, in 10 or more locations.	Increase deployment of black liquor gasification by a factor of 20.	
Demonstrate use of biosynthesis gas as a significant component of chemicals and materials conventionally made from petroleum.		
Demonstrate advanced gasification and biosynthesis gas technology suitable for integrated use for power generation on large scale and in distributed systems, in a biorefinery, and for the production of chemicals.	Develop and deploy advanced gasification and biosynthesis gas technology.	
Demonstrate the economic viability of markedly more efficient fermentation processes for producing liquid fuels and chemicals.	Identify/design microorganisms/enzymes with 10-fold to 1,000-fold improvements in efficiency (including the use of extremophiles).	
	Develop technology to produce multiple value-added products from lignin, and reduce the cost of producing sugar from lignocellulosics to $0.03 to $0.04 per pound.	

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Technology: Processing & Conversion (cont.)

Goal 3 (cont.)

Develop cost-effective and environmentally responsible conversion technologies for a suite of biobased products and output types.

Tactical Actions

By 2010	By 2020	By 2050
Explore and define modular and distributed systems approaches to production of a suite of bioproducts and bioenergy.	Develop cost-competitive biomass-derived hydrogen production processes.	
Implement life-cycle analysis (LCA) to evaluate all new conversion methods for possible environmental impacts to identify and quantify environmental benefits.	Create interrelated networks of biological and thermal conversions to utilize 95% or more of all input volumes.	***Milestone:*** *All new methods have zero residual waste streams.*

Strategic Result 2

Develop and deploy commercial biorefinery concepts.

Tactical Actions

By 2010	By 2020	By 2050
Develop benchmarks and standards and create technology tests for evaluation of integrated approaches and best operational scales for biorefining.		
Implement demonstration facilities for biorefining with multiple output types: power, fuels, chemicals and products.	Deploy significant number of commercial facilities for biorefining with multiple output streams: power, fuels, chemicals, and products.	Ensure that multiple commercial large and modular biorefineries are in operation across the country with no residue waste stream issues.

Technology: Product Uses & Distribution

Strategic Result

Achieve advancements in technologies to expand markets, create new markets, and improve product distribution.

Tactical Actions

By 2010	By 2020	By 2050
Identify the portfolio and understand the fundamental structure/property relationships of plant molecular constituents to potential biobased materials, such as hydraulic fluids, lubricants, other fluids, liquid fuels, plastics, composites, coatings, adhesives, chemicals, and other products.	Establish detailed knowledge of structure-function relationships for 10 or more plant molecular constituents, and identify product uses.	Engineer (from nature or designed) 10 or more specific molecular structures based on desired functionality; 10 or more novel materials.
Develop and commercialize 10 or more new biobased chemicals, products, or materials with sustainable economics.	Commercialize 20 or more new biobased products or materials with sustainable economics.	Commercialize 200 or more new biobased products and materials with sustainable economics.
Develop standards for biobased products and bioenergy, and a suite of analytical tools for characterization and quantification.		
Develop and field-test technologies to validate more flexible use of a broad range of biobased feedstocks.	Deploy high-efficiency combined-cycle biomass gasification, and technologies for low-emission biorefinery operations.	
Develop, field-test, and optimize design of prototype integrated biomass gasification-fuel cell systems and establish their costs.	Deploy fuel cell technology for biomass-derived fuels for stationary and mobile use.	
Demonstrate 50MW or higher capacity IGCC power plants with 45% or higher electrical efficiency.	Produce electricity on a commercial scale from biomass at an average cost of $0.05/kWh or less.	
Demonstrate the production of biomass-derived fuels at a cost of $0.60/gallon or less.	Produce biomass-derived fuels on a commercial scale at a cost of $0.60/gallon or less.	

[DEL: This page redundant with Goal 3, Processing & Conversion]

Market Development

Ultimately, the biobased products and bioenergy industry will be dynamic and self-supporting. Returns to our nation will include enhanced energy security and environmental quality, stronger rural economies, new domestic employment opportunities, enhanced balance of trade, and a strong position in global markets for biobased technologies.

However, strategic market development efforts must be made in the near term if our nation is to achieve the visionary goals. This section of the **Roadmap** outlines high-priority actions for building significant markets for biobased products and bioenergy. In particular, it highlights the need to develop market preference for biobased products and bioenergy and to attract substantial infrastructure investments.

Strategic results, goals, and tactical actions address the following:

- Defining market requirements that will drive design of plants, trees, and other biomass sources.
- Promoting market demand for feedstocks production and delivery.
- Attracting investment in integrated facilities, including biorefineries.
- Progressively increasing market share as well as the size of overall markets for biobased products and bioenergy.

Infrastructure concepts and long-term supply contracts will be necessary to ensure supply to the industry and to help ensure value distribution to the growers. Establishment and deployment of biorefineries and understanding the business arrangements and value chains involved will optimize opportunities for biomass use for products, fuels, and power.

The power market is a very attractive opportunity right now. There is demand for increased supply, and deregulation opens interesting options for biobased power. Technology is available to take advantage of this market now, and new technology is being developed to take even greater advantage of these opportunities.

Risks are involved in the first full-scale operations of any new technology. Market development includes creating ways to mitigate or diffuse these risks for the emerging biobased industry.

The federal government itself represents a significant market (20% of the GDP). One way to help create the biobased market is through preferential biobased federal purchasing. Establishing federal and national biobased labeling and certification can also help spur market development.

Market Development

Strategic Result 1

Define market requirements that will drive design of plant-based feedstocks.

Tactical Actions

By 2010	By 2020	By 2050
Identify the primary characteristics of plant feedstocks needed by the biofuels, biopower, and bioproducts markets, and implement plant sources or modification types to meet these requirements.	Identify advanced features that enhance the performance of plant-based feed-stocks for various biobased products and bioenergy uses, and develop methods to stack these traits into relevant species.	

Strategic Result 2

Promote market demand for feedstock production and delivery (harvesting, preprocessing, transportation).

Goal 1

Create tools and mechanisms to allow producers and users to evaluate business decisions relative to production of biobased feedstocks.

Tactical Actions

By 2010	By 2020	By 2050
Create and establish Internet-based trading system.	Establish decision-support system to dynamically compare land-use among food, feed, and fiber biomass.	

Goal 2

Provide incentives and implement mechanisms that encourage market development for biobased feedstocks.

Tactical Actions

By 2010	By 2020	By 2050
Demonstrate economic viability and build case for attracting investment in feedstock infrastructure.	Identify remaining factors limiting further growth of bioproducts and bioenergy.	
Create financial incentives that support consistent use of biobased feedstocks.	Achieve production systems and input materials that do not require subsidies.	
Develop systems to capture value of total inputs: e.g., high-value co-prod-ucts, multi-stream biorefineries.	Widely deploy multi-input, multi-stream biorefineries.	

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Market Development (cont.)

Goal 2 (cont.)

Provide incentives and implement mechanisms that encourage market development for biobased feedstocks.

Tactical Actions

By 2010	By 2020	By 2050
Establish high-value-added product markets and systems to justify initial high costs and risks.	Significantly expand high-value-added markets and supply contracts.	
Establish long-term supply contracts for feedstocks.		
Develop insurance plans and an early trading system that mitigates risk and provides liquidity in the market.	Establish a biomass commodity trading exchange.	
Provide incentive mechanisms for formation of vertically integrated coop-eratives: production through utilization.		

Strategic Result 3

Attract investment in integrated facilities by demonstrating the commercial and market viability of biopower, combined heat and power, biofuels, and biobased products, including the biorefinery concept.

Tactical Actions

By 2010	By 2020	By 2050
Target deployment of 50-100 commercial biorefineries or other large-scale biobased operations.	Target deployment of 1,000 or more commercial biorefineries or other large-scale biobased operations.	Incorporate feedback of market infor-mation on co-product needs in the redesign of input streams.
Demonstrate 2 or more power facilities with 5 to 50MWe capacity by 2005, pro-ducing electricity from biomass at an average cost of $0.05/KWh or less.	Generate power at 50MW scale or greater at 80% of commercial biorefineries.	
By 2005, develop ways to reduce and distribute the economic risks of the first several processing and conversion operations.	Ensure market-based pricing and risk-management mechanisms are in place to support start-up and expansion of processing and conversion facilities.	
	Demonstrate that commercial process-ing operations are self-financing (no subsidies).	

[DEL: Tactical goals under Result 3 inconsistant with Goal 3, page 17.]

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Strategic Result 4

Progressively increase market share of biobased products and bioenergy, as well as the size of the overall market wherever possible.

Tactical Actions

By 2010	By 2020	By 2050
Provide federal buy-down incentives to promote technology commercialization.	Implement policy requiring all federal agencies to purchase 20% biomass-derived power, fuels, and products.	***Milestone:*** *All federal sites purchase 40% biomass-derived power, fuels, and products.*
Establish national labeling and certification programs quantifying value-added benefits of biobased products and bioenergy.		
Develop infrastructure and markets for biofuels (ethanol, biodiesel, methanol, gasoline substitutes, and hydrogen).	Increase infrastructure for biofuels usage in transportation to support a 10-fold increase.	
Develop and monetize full life-cycle analysis models for comparative real cost to market.	Based on full life-cycle analysis, define optimum combinations of bio- and fossil-based feedstocks for portfolio of outputs.	

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Policy and Education

Supportive government policies and educational platforms will be essential in building our nation's biobased future. An effective policy framework will reduce market barriers to biomass, incentivize private investments, and establish science-based standards for bioproduct quality, performance, and safety. It will ensure access for small, dispersed power generators to interconnect to the electricity transmission and distribution grid. The federal government can also play a vital role in education and outreach, providing information on the benefits of biobased products and bioenergy to states, communities, farms, industries, and consumers. Above all, significantly increased levels of public investments will be needed for research and development, and for risk-sharing in first-of-a-kind commercial-scale demonstrations.

This section of the **Roadmap** addresses the importance of these drivers and defines as high-priority needs:

- Steadily increasing federal funding for a full spectrum of RD&D—reaching, by 2010, an annual level approximating $1 billion.
- Establishing a supportive framework of policies, mechanisms, and science-based regulation—aligned across the national and local levels.
- Creating high levels of public awareness of the societal value of biobased products and bioenergy.
- Creating a platform of education and training that ensures a high level of understanding of the benefits of a biobased economy, and sufficent numbers of scientists, engineers, and business people with skills and know-how in critical disciplines and processes.

Policy and Education

Strategic Result 1

Steadily increase federal funding for a full spectrum of research, development, and demonstration—from basic science to commercial-scale pilots—reaching, by 2010, a level approximating $1 billion, equivalent to the public investment in RD&D of fossil fuel technologies and chemical sciences.

Goal 1 (now-ongoing)

Federally support widespread basic and applied research in plant science, biotechnology, functional genomics, bio- and thermal processing, and other relevant sciences and technologies.

Goal 2 (now-ongoing)

Maximize R&D results through ongoing coordination across federal agencies, and integration across private- and public-sector research projects (building on the efforts of the Biomass Research and Development Board).

Goal 3 (now-2010)

Provide federal cost-sharing to support commercial-scale demonstrations of first-of-kind facilities as a means of mitigating risks and encouraging private-sector investments.

Strategic Result 2

Establish a supportive framework of policies, mechanisms, and science-based regulation—aligned across the national and local levels—to encourage private-sector investments in technology and infrastructure.

Goal 1 (now)

Through life-cycle analysis (LCA) and other approaches, quantify the full costs and benefits of biobased products and bioenergy as the basis for appropriate supporting policies and regulations.

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Policy and Education (cont.)

Strategic Result 2 (cont.)

Establish a supportive framework of policies, mechanisms, and science-based regulation—aligned across the national and local levels—to encourage private-sector investments in technology and infrastructure.

Goal 2 (now-ongoing)

Implement a science-based regulatory framework—aligned across agencies and across national and local levels—that decreases barriers to the production and marketing of bioenergy and biobased products.

Tactical Actions

- Survey relevant policy and regulatory issues across federal and state governments (e.g., agriculture, forestry, energy, waste, air, water, soil, environmental, recycling standards).
- Address regulatory barriers and incentives (e.g., appropriate carbon trading, appropriate use of CRP and federal lands, etc.).
- Ensure equitable access to the electricity grid for small, geographically dispersed power generators.
- Develop approaches for fast-track decision-making and streamlined procedures and permitting for promising new technologies, including flexibility on timing of environmental performance (e.g., the EPA XL program).
- Address EPA's New Source Review (NSR) restrictions for co-firing with biomass (by 2002).
- Establish standards for use of ethanol in oxygenated fuels (immediate).
- Encourage development of portfolio standards for fuels, power, and products.
- Demonstrate the safety of biotechnology in feedstock production and biomass processing, as the foundation for supportive policies and regulations.

Goal 3

Create incentives to facilitate early commercialization of enabling technologies and to encourage market development.

Tactical Actions

- Implement incentives (e.g., tax policies, buy-downs) to encourage private-sector investments in initial commercial applications of new technologies, and to ensure opportunities for small entrepreneurial ventures (e.g., credit access).
- Establish federal procurement policy on biopower, biofuels, and bioproducts purchasing, based on greatest lifecycle value.

Strategic Result 3

By 2010, create high levels of awareness of the societal value of biobased products and bioenergy through public education and communication campaigns.

Goal 1 (now)

Educate federal and state legislators on the benefits of biobased products and bioenergy and the need for supportive policies.

Goal 2 (now)

Implement a public education campaign that highlights the life-cycle benefits of biobased products and bioenergy and builds consumer preference for these products.

Goal 3 (now)

Establish ongoing communications with selected stakeholder groups (e.g., the environmental community).

Goal 4 (by 2010)

Establish a campaign to support the export of bioenergy and biobased products and related technologies.

Strategic Result 4

Create a platform of education and training that ensures high levels of understanding and skill in sciences, processes, professions, and trades related to biobased products and bioenergy.

Goal 1

Universities—Create multidisciplinary curricula, training centers, and postdoctoral programs for biobased product and bioenergy processes; offer advanced degrees in such areas as integrated renewable resources and biorefining.

Goal 2

K-12—Establish a basic curriculum in biology, sustainability, and bioenergy and biobased products.

Goal 3

Professionals—Educate biomass producers on optimum production, harvesting, collection, and transport methods; develop on-line database resources on feedstock production and collection methods and on renewable input uses; establish education of trades and professionals (e.g., welders and other trades that will build biorefineries; plant managers and operators).

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Appendix 1

Definitions

barrel (bbl)
Equivalent to 42 U.S. gallons. The energy in one bbl is equivalent to 5.8 million Btu. One quad is about 172 million bbl.

biobased resources
Material and/or energy derived from biological origins within biological time.

bioenergy
Energy, fuel, or feedstocks derived from biomass or biobased source(s).

biofuel
A liquid fuel made from biomass via either thermal conversion (e.g., gasification) or biological conversion (e.g., enzymatic and fermentation combinations). Products such as ethanol, methanol, or methyl soyate (biodiesel) are typically used as transportation fuel additives.

biomass
Material derived from biological origins within biological time; or, alternatively, any mass created through photosynthesis to fix carbon. Traditional biomass is often used to denote lignin- and cellulose-containing materials.

biopower
Electricity or a storage form of energy from biomass.

British thermal unit (Btu)
Measure of energy based on the amount of heat required to raise the temperature of one pound of water from 59°F to 60°F at one atmosphere pressure.

co-firing
Combustion of mixed materials. For example, wood chips with coal.

cogeneration
The production of electricity plus another energy type. For example, locally produced steam may drive an electricity-generating turbine and subsequently be used for heating at other locations in the facility.

combustion
The oxidative burning of material, typically under normal atmospheric pressure. Internal combustion would be under pressure as in an engine.

fossil fuels
Coal, natural gas, crude oil, etc. — derived from biological sources but in a geological timeframe.

gasification
Thermal conversion of biomass using air, oxygen, and/or steam to produce either a low or medium calorific value fuel gas or synthesis gas. The fuel gas could drive a combined-cycle turbine for power production, and the synthesis gas could be further processed to produce liquid fuels, chemicals, and/or products.

horsepower
A measure of mechanical energy output. Conversions 1 hp = 745.7 watts = 2,545 Btu/hr.

pyrolysis
The decomposition of biomass by heating at very high temperatures in the absence of oxygen. The production of char (solid), pyrolysis oil (black liquid), gas (methane, etc.) depends on the conditions of heat, pressure, oxygenation, etc.

quad
A quadrillion Btu (10^{15}, British thermal units).

renewable energy
Energy derived from a source that can be regenerated or is inexhaustible. For example, biomass, hydropower, wind, solar, or geothermal.

renewable resources
Resources derived from plant-based primary-energy-capture mechanisms in an annual or few-year timeframe, or from other regenerative sources. Could be energy, structural material, or chemicals.

silviculture
A branch of forestry dealing with the development and care of forests.

watt
A basic unit of power equivalent to 3.413 Btu/hr. 1 kilowatt hour (kWh) is a measure of energy equal to using 1,000 watts for one hour.

Appendix 2

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